

Evolution of Task Partitioning in Swarm Robotics

Eliseo Ferrante¹, Edgar Duéñez-Guzmán¹, Ali Emre Turgut², Tom Wenseleers¹

¹Laboratory of Socioecology and Social Evolution, KU Leuven, 59 Naamsestraat, 3000 Leuven, Belgium

²Mechatronics Department, THK University, Turkkusu Campus, 06790 Etimesgut/Ankara, Turkey
eliseo.ferrante@bio.kuleuven.be

Abstract Task-partitioning refers to the process whereby a task is divided into two or more sub-tasks. Through task partitioning both efficiency and effectiveness can be improved provided the right environmental conditions.

We synthesize self-organized task partitioning behaviors for a swarm of mobile robots using artificial evolution. Through validation experiments, we show that the synthesized behaviors exploits behavioral specialization despite being based on homogeneous individual behaviors.

Introduction Social insects exhibit astonishing levels of social organization (Wilson, 1971). One of the organizational paradigms used by social insects is division of labour, whereby they perform complex tasks by having parts of the colonies specializing into sub-tasks (Wilson, 1971). Two key concepts are fundamental in division of labour: task partitioning, which is the process whereby individuals divide a complex task into simpler sub-tasks (Ratnieks and Anderson, 1999); and task allocation, whereby individuals specialize to perform one among these sub-tasks.

We study task partitioning in the context of swarm robotics. Swarm robotics aims at designing collective behaviors for swarms of autonomous robots based on self-organization and swarm intelligence principles rather than on centralized or global coordination (Brambilla et al., 2013). Through task partitioning, swarm robotics systems can increase flexibility and performance, better exploit specialization and reduce interference (Pini et al., 2013).

Differently from existing work mainly realized through hand-coded design methods (Pini et al., 2013), in this paper we use evolutionary swarm robotics methods (Trianni, 2008). We tackle a foraging task, a classical benchmark problem in swarm robotics (Brambilla et al., 2013). We show that the swarm can evolve to self-organize into task partitioning in the considered environment.

Evolutionary method and experimental setup We use GESwarm (Ferrante et al., 2013), which allows the synthesis of readable and reverse engineerable individual behaviors that self-organize into the desired collective behaviors.

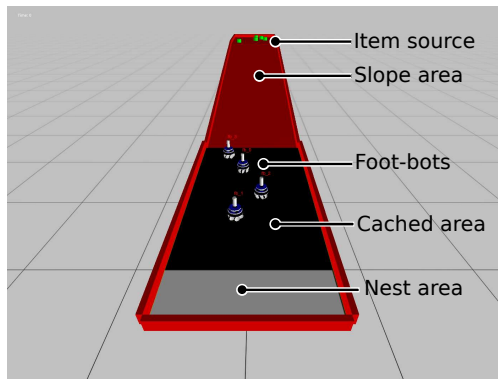
GESwarm is based on Grammatical Evolution (GE)(O’Neill and Ryan, 2003) and uses a grammar that can express a rich variety of swarm robotics behaviors. GESwarm automatically combines existing low-level individual behaviors into more complex strategies, and produces a set of readable rules that switch between low-level behaviors in response to internal or external stimuli.

We consider foraging in the environment shown in Figure 1a. Robots need to collect items from a region that we call *source area* and bring them to a region that we call *nest area*. In the source, 5 objects are present and are replaced each time robots pick them up. A light source is placed far beyond the source. The light allows the robots to navigate using their low-level behaviors: they perform phototaxis to go towards the source and anti-phototaxis to go towards the nest. Robots can also do random walk. An obstacle avoidance behavior is present and always active. The source is connected to the nest through a *slope area* and a *cache area*. Robots climbing the slope upwards navigate at a reduced speed. Items dropped on the slope slide down, stopping at the cache. Existing items in the cache can be pushed further down by new sliding items. Thus the cache can be filled almost uniformly when many objects are dropped on the slope.

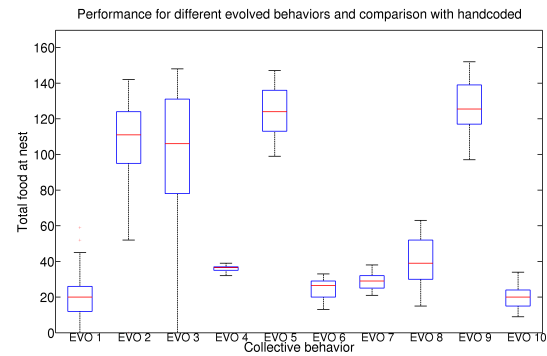
We use GEVA for grammatical evolution¹. We execute 10 evolutionary runs consisting of 2000 generations and 100 individuals. Individuals are individual behaviors executed by all robots in each swarm. Each collective behavior produced by these individual behaviors is evaluated 3 times in a swarm of 4 robots. We use a single-point crossover with probability 0.3 and a mutation probability of 0.05. We choose a generational-type of replacement with 5% elitism and a roulette-wheel selection mechanism.

The fitness function in the initial part of the evolution is the number of items collected by the best robot (fitness *A*). This allows for neutral variation: evolution can explore solutions based on behavioral specializing without a detrimental effect on the fitness, producing a smoother fitness landscape. In the final phase of the evolution, the fitness is set to the total number of collected items (fitness *B*), the actual objective

¹GEVA homepage, <http://ncra.ucd.ie/Site/GEVA.html>



(a)



(b)

Figure 1: Experimental setup and results. (a) A snapshot of the ARGoS simulator that illustrates our experimental setup. (b) Performance of the evolved behaviors.

of foraging. The fitness is smoothly changed from A to B during intermediate phases of the evolution.

Results Figure 1b shows the results of evaluating each evolved collective behaviors 30 times. To judge whether the task was partitioned or not, we track each item and we count how many items were transported by more than one robot. In 8 out of the 10 evolved collective behaviors, items were transported by more than one robots. This corresponds to a task partitioning strategy where some robots collect items and drop them on the slope (*dropper* robots) and other robots collect items from the slope and bring them to the nest (*collector* robots). Only in two cases (EVO 4 and 7), all items were transported by only one robot. This corresponds to a standard foraging strategy where all robots collect items from the source and bring them to the nest (*forager* robots). This behavior is also characterized by lower performance in the considered environment (Figure 1b).

The evolved collective behaviors with the highest performance (i.e. EVO 2, 5 and 9) are based on task partitioning. We report two example videos² showing the performance of the best evolved behavior, EVO 9, validated with 4 and 20 robots, respectively. The videos show that the evolved strategy is characterized by a dynamic allocation of sub-tasks, where robots continuously switch between the *dropper* and *collector* roles. This adaptive strategy closely resembles the one used in Pini et al. (2013) in a related scenario.

Conclusions We successfully evolved self-organized task partitioning in a swarm of mobile robots using grammatical evolution. We showed that the best evolved strategy is characterized by a dynamic allocation of sub-tasks. In fu-

ture work we plan to perform a comparison with optimal and state-of-the-art task-partitioning strategies (Pini et al., 2013), and to study modularity, phenotypic plasticity and multi-level selection in the context of task partitioning.

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²Supplementary material - <http://bio.kuleuven.be/ento/ferrante/FerranteSupp2013-001/>